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The renewable energy market in Brazil: Current status and potential

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ABSTRACT

Renewable energy offers a range of options with which to meet the growing demand for energy, particularly in the context of the pursuit (especially in developing countries) of economic development which takes into account social and environmental issues. Brazil has abundant natural sources of renewable energy, such as wind and solar power, hydraulic energy, small hydroelectric plants, ethanol and biodiesel. These sources form part of the Brazilian strategy aimed at satisfying the demand for 6300 MW of fresh capacity per year arising out of projected economic growth of 5.1% per year over the next 10 years. Renewable energy sources currently provide 47.2% of the internal supply of primary energy in Brazil. Brazil has been pursuing a strategy of maintaining its renewable energy matrix and developing and providing incentives for further low carbon initiatives.

In this study we set out an overview of the renewable energy options available in Brazil, their current status, the main positive results obtained to date and future potential. We describe the market for renewable energy in Brazil and examine specific public policies aimed at overcoming barriers to this market, thereby promoting its consolidation and expansion.

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1. Introduction

The use of fossil fuels has made possible a contemporary world of high agricultural and industrial, by means of mechanization and the substitution of manual labor. This in turn has led to a reduction in rural population and a migration of workers to the service sector, with a corresponding increase in cultural and commercial exchange in an increasingly diverse world. All these advances have led to significant individual and collective benefits, such as the reduction or substitution of arduous manual labor, an increase in lifespan and health, improved educational opportunities, increased income, greater individual freedoms (democracy) amongst others.

According to Longo [1], the most significant social impacts brought about by scientific and technological advances include the

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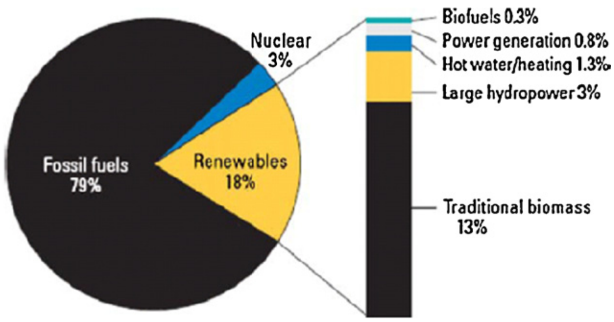


Fig. 1. Participation of sources of energy in final consumption (world). Source: Kumar et al. [4].

increase in life expectancy, population growth and the decrease in working hours, particularly over the past two centuries. This has in turn led to an increase in the time available for leisure, with technological and scientific advance being associated with wider and deeper use of energy resources.

In recent years academic debate has highlighted concerns related to the perpetuation of energy consumption patterns based on fossil fuels, and the implications of this for society. The worrying triad of a shortage of fossil based resources, energy related safety issues and climate change requires that urgent attention be given to the current energy supply structure[1] and a fresh trajectory sought. This requires, amongst other things, an increase in the share of renewable energy sources in the world energy matrix.

At present the world continues to consume mainly fossil fuel, which forms 79% of the matrix (Fig. 1). This situation is particularly concerning given the scenario of dwindling resources, as highlighted by the International Energy Agency [3], which forecasts that fossil fuel reserves will be exhausted in less than a 100 years from now.

The continued depletion of global fossil reserves and recent forecasts as to exhaustion of supplies, ranging from 47 to 131 years (Table 1), together with concerns as to the environmental impact of their processing and use, giver rise to a need to reverse current trajectories. Development and promotion of the use of renewable energy[2] is one of the strategies relied upon in the search for sustainability.[3]

One ramification of the increase in demand for fossil fuel, unmatched by a corresponding increase in supply, is higher prices in the future. The projections of the International Energy Outlook [6] indicate that the price of oil on the international market will reach U$$ 133 per barrel in 2035, in the reference scenario. The trend of on-going high prices for oil is likely to aggravate the imbalance in the trade balance of countries which are dependent on the import of oil and its derivatives. This is particularly true of countries with low international reserves. Macroeconomic imbalances will, the result of inflation or a reduction in economic activity will in turn, lead to reduced tax revenues and problems of public investment.

The renewable sources of energy offer an opportunity for the planet to reduce emissions and to return to an 'inclusive' economic trajectory, aligned with environmental equilibrium as was previously the case in the civilization process of humanity based on the use of renewable energy convertors.

The aim of this study is to set out the current situation of the market for renewable sources in Brazil, identifying its principal characteristics, opportunities and challenges. In terms of the structure of the market we seek to set out the key questions pertaining to the promotion of the market and the principal public policy instruments involved. This article is divided into five sections. Section 2 sets out the Brazilian energy context. Section 3 highlights the issues relevant to renewable sources in Brazil, sub-divided by sources/technologies. In Section 4 we list the current development strategies and the future perspectives for renewable energy sources in Brazil. Section 5 sets out our conclusions and recommendations.

2. The Brazilian energy context

Brazil has continental dimensions, possessing an area of 8.5 million km^2, and a population of 191 million people. Per capita income is US$ 10,414 (Purchasing Power Parity – PPP 2010), the country is governed democratically and has friendly relations with its neighbors. There is not perspective of ethnic or religious conflict. It is the most industrialized and diverse country in Latin America with a GDP of 2.017 trillion (PPC). According to The Economist [7], the Brazilian economy is expected to expand from the ninth to the fifth largest in the world by 2025. Brazil also possesses major potential in terms of natural resources and the expansion of an agro-industry geared towards the external market as well as the potential of its renewable energy resources (solar, wind, biomass and hydraulic) and pre-salt fossil resources (destined primarily for export).

Whilst experiencing the world's second largest growth in GDP in the twentieth century with a 127-fold increase in per capita income, Brazil has grown unequally. It still has a major social deficit in the 21st century, despite several advances in recent years, particularly in relation to the most vulnerable social groups. These advances are the result of socially oriented public policies, for example: 16 million Brazilians rose above the poverty line between 2005 and 2009 [8], the equivalent of the combined populations of Denmark, Uruguay and Paraguay; the unacceptable permanence of high concentration of income was altered, with a reduction in the Gini co-efficient from 0.593 in 2001 to 0.543 in 2009 [8]. Furthermore, around 12 million Brazilians obtained access to electricity [9], so that there is now almost universal access. Credit increased in relation to the GDP, so that, according to IPEADATA [8] the rate of credit operations in the public and private sectors passed from 26.86% of the GDP in 2002–46.08% of the GDP in 2010; there was also an increase in the provision of education, and in educational standards, an increase in income transfer, particularly by means of the Bolsa Família social program[4]; a 55.48% recovery in the value of the minimum wage, in real terms, between 2002 and 2010 [8]. Employment increased, and there was a reduction in 'informal' (unregistered) jobs. In 2002 the unemployment rate was 11.7%, whilst in 2010 the rate fell to 7% [8]. The fall in unemployment was particularly noticeable in relation to women.

[1] Furthermore, there is an additional question, which is rarely addressed in the literature: possibility of distributed generation: as a means of social inclusion, providing a major segment of the world population with access to electricity, in addition to addressing social and environmental sustainability issues. 1/3 of the world population, approximately 2 billion people, do not have access to electricity. According to Pereira et al. [2], access to electricity is one of the key elements of economic development and reduction of rural poverty, and as such should be considered a fundamental and absolute legal right.

[2] Kumar et al. [4] state that approximately 70% of the emissions related to global warming are related to energy, principally the burning of fossil fuels for heating, electricity generation and transport. Many countries have the opportunity to reduce global warming gases to a minimum by adopting measures aimed at energy conservation by more efficient use, better energy management, lower carbon emissions (clean technologies), as well as changes in lifestyle/standards of living.

[3] We acknowledge that both the promotion of renewable energy sources and adoption of energy efficiency are essential strategies in facing the planet-wide challenge of "de-carbonizing the economy". We have limited the focus of this paper, however, to renewable energy.

[4] According to the Social Development Ministry [12], funding of around US$ 7 billion was made available in the year 2010, up to October, covering 13 million families.

Table 1
Global reserves and availability of major fossil energy resources.

Category item	Oil (+oil sands)	Natural gas	Coal
Total reserves (end of 2008)	1408 billion barrels	185 trillion m^3	826 billion tons
Yield (2008)	29.9 billion barrels	3.1 trillion m^3	6.28 billion tons
Available years	47 years	60 years	131 years

Source: BP Statistical Review of World Energy [5].

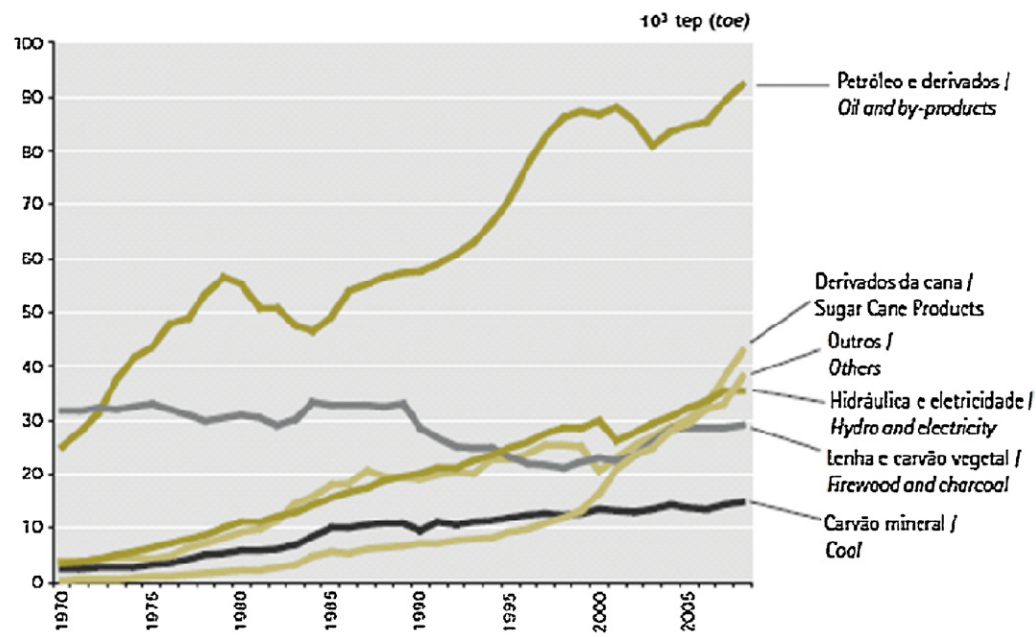


Fig. 2. Internal offer of energy (Brazil – 1970/2009).

Source: EPE [13].

There was an increase in the demand for energy the energy sector, as a natural ramification of these and other actions. In this context the 2010–2019 [10] forecasts an annual GDP growth of 5.1% over the next 10 years. This will require an investment of US$ 564 billion in the energy sector over the same period. In this climate of a major expansion in the internal offer of energy, a strategy is being sought to ensure the maintenance of the renewability of the Brazilian energy matrix, which, in the past, was guaranteed by parallel technological routes based on opting for ethanol and the use of hydraulic resources (Fig. 2), and, in recent years in the direction of the use of wind resources and the production of biodiesel.

Even taking into account the period of continuous expansion in the supply of energy (2010–2019), final per capita consumption (TOE/inhab/year) will remain low, increasing from 1.17 TOE/inhab/year in 2010 to 1.77 TOE/inhab/year[5] in 2019 indicating an annual growth of 5.2%, according to information taken from the Ten Year Expansion Plan 2019 [10]. This information indicates the need for a prolonged period of further expansion of energy supply, given the major social challenges which persist in the country, including the need to amplify the provision of basic services such as electricity, water access and sanitation. According to [10] to assess the potential growth in electricity demand, It's possible to compare the average electricity consumption of Brazil with that of some developed countries or regions in the world, with a bit more than 2000 kWh/capita, Brazil's electricity consumption is far behind that of the US (12,000 kWh/cap) or France (almost 8000 kWh/capita). Therefore is expected that the electricity consumption will grow from 2 to 4 times in the coming years, depending widely on the energy politics and economics of Brazil.

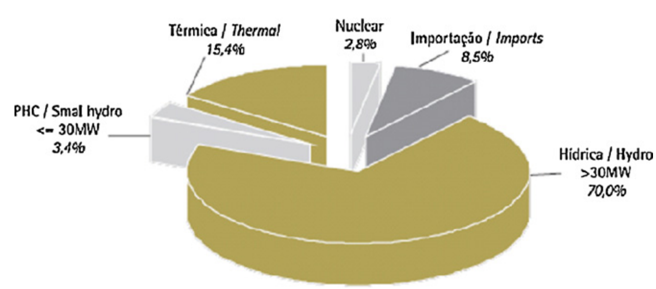
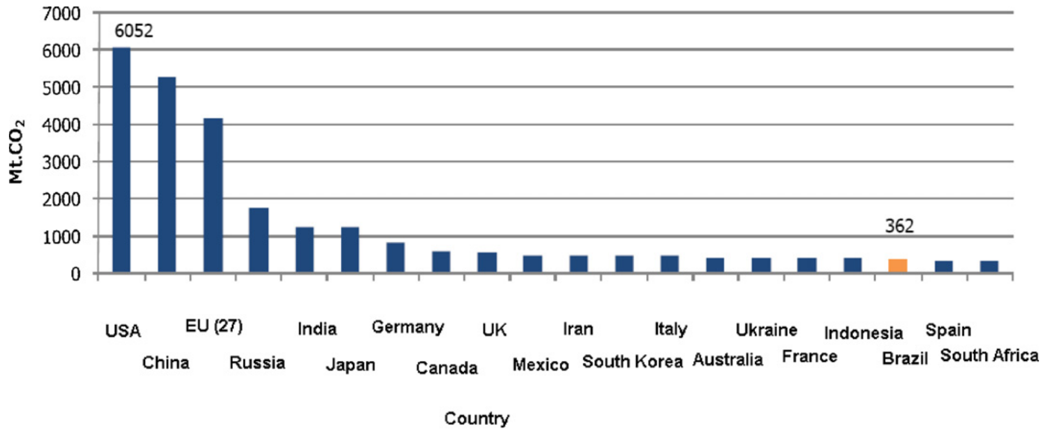


Fig. 3. Internal offer of energy per primary source (Brazil – electricity).
Source: EPE [13].

Figs. 3 and 4 illustrate the participation of different sources in the internal supply of electricity in Brazil and in the world respectively. It can be seen that Brazil has an electricity generation matrix based mainly on renewable sources, with internal hydraulic generation accounting for over 70% of the offer. Adding imports,[6] which are also, essentially, from renewable sources,

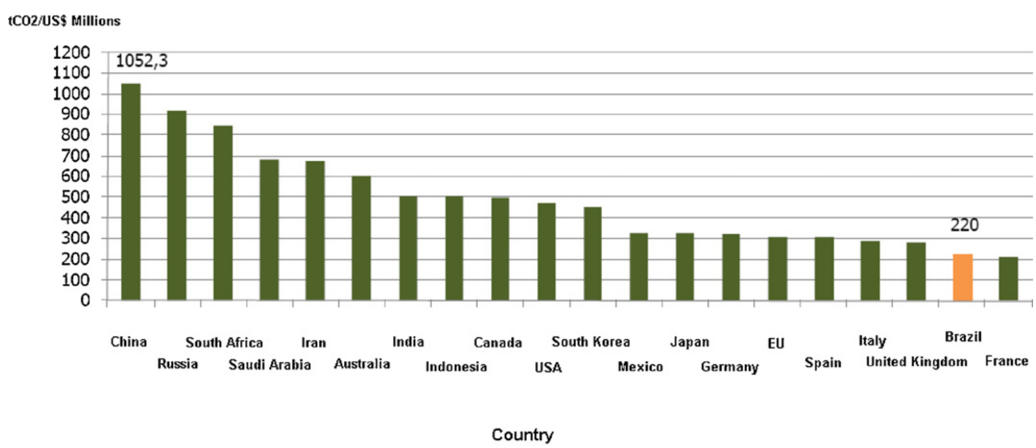
[5] In most countries where the per capita consumption of commercial energy is under 1 ton of oil equivalent (TOE), illiteracy, infant mortality and fertility rates are high, whilst life expectancy is low. It would therefore appear that rising above the 1 TOE/capita bar is essential to development. To the extent that the per capita consumption of energy increases above 2 TOE or more, as is the case in developed countries, social conditions improve considerably. The average per capita consumption in the industrialized countries of the European Union is 3.22 TOE/capita; the world average is 1.66 TOE/capita [14].

[6] In 2009, 42.901 GWh of electricity was imported, mainly from Itaipu Binacional (Brazil-Paraguai) [13].



Graph 1. Principal emitters of greenhouse gases (energy).

Source: MME [11].



Graph 2. Principal emitters of greenhouse gases in terms of intensity of CO_2 in the economy.

Source: MME [11].

approximately 80% of Brazilian electricity comes from renewable sources. Furthermore, part of the Brazilian thermal generation is based on biomass. The world average for the share of renewable sources in electricity generation is only 15.6%.

The advantages of the decision taken in the past to opt for the renewable technological route are apparent nowadays. Brazil is ranked 18th worldwide (Graph 1) in terms of CO2 emitted for the purpose of energy. Comparison of the data on the emission of greenhouse gases in Brazil with the socioeconomic data such as population and GDP shows that the level of Brazilian emissions is considerably lower than that of the main emitters. Statistically, each EUA citizen emits around 10 times more greenhouse gas (20.5 t CO_2/hab.) than a Brazilian (2.0 t CO_2/hab.). Furthermore, comparison of greenhouse gas emissions (excluding emissions caused by deforestation) with GDP shows that, in order to generate US$1 million GDP, China emits 1.052 t CO_2, the United States emits 473 t CO_2 and Brazil emits 220 t CO_2 (Graph 2).

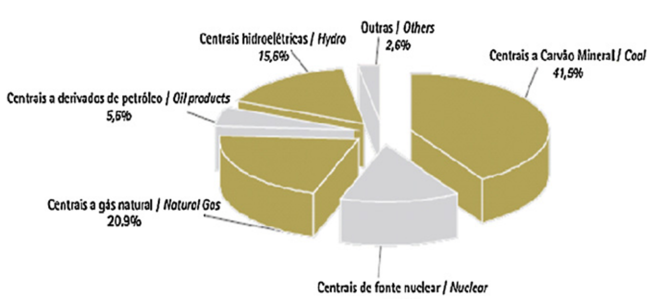


Fig. 4. Internal offer of energy per primary source (World – electricity).
Source: EPE [13].

Despite the fact that Brazil is not, currently, a major emitter of greenhouse gases (GHG) its efforts to maintain its technological routes at a low carbon level are laudable, given the increasing challenges posed by global warming. It should however be noted that in the medium and long terms it is likely that Brazil will increase its GHG emissions given the direct relationship between the socially inclusive economic development pursued in recent years and the emission of greenhouse gases. In these circumstances, it is necessary to adopt a development model that is distinct from that of developed countries and which has the combined aim of achieving economic growth and fair distribution of income allied to environmental sustainability. Renewable energy sources are a determining vector in the quest for this aim.

3. Renewable energy in Brazil

Renewable energy is, by definition, sustainable and clean and in addition offers the opportunity to tackle the increasing depletion of fossil resources and the associated environmental impacts [15]. Brazil has therefore sought to maintain its strategy of maintaining its historically renewable matrix, allied with its policy of

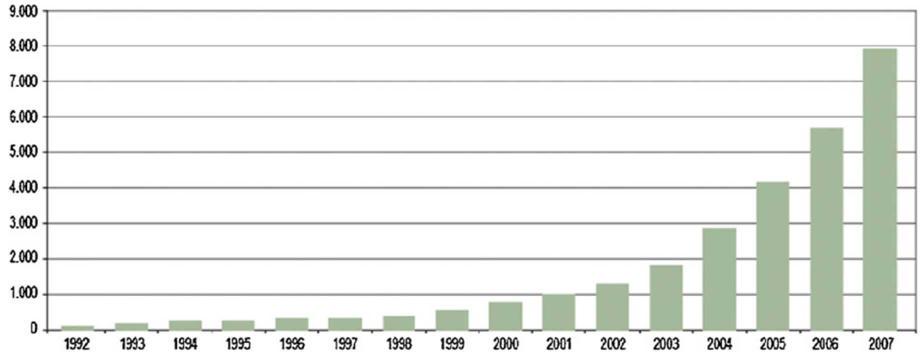


Fig. 5. Installed potency of photovoltaic cells in the world (MW).

Source: IEA [17].

energy safety,[7] developing and encouraging initiatives designed to increase the internal offer of renewable energy, in association with the promotion of a low carbon economy.[8] However, moves towards the consolidation of other sources of renewable energy, such as wind and solar power in addition to hydraulic energy and biomass, are still incipient.

3.1. Solar energy

Solar energy is the most abundant energy resource on the planet and is available for direct (solar radiation) and indirect (wind, biomass, hydraulic, etc.) use. The Brazilian approach is directed towards the use of solar energy in both ways, for both heating and lighting, using two routes: the thermal route mainly for heating and for the generation of electricity, in particular via photovoltaic panels for various uses such as lighting, pumping and communication.

Solar energy still plays a minor role in the world energy matrix but its share increased over 2000% between 1996 and 2006. In 2007, the total installed potency reached 7.8 thousand MW, according to a study undertaken by the *Photovoltaic Power Systems Program* [17]. Fig. 5 sets out the evolution of installed solar potency in the world, for electricity production, from 1992 to 2007.

In relation to the use of photovoltaic solar energy, more recent data released by SolarBuzz LLC [18], show that 2009 saw an expansion of around 7.3 GW from photovoltaic installations in the world, a 20% increase on 2008 figures. The estimate for 2010 is a total of between 8.4 and 13.1 GW.

According to [19], almost all the photovoltaic systems in Brazil are not connected to the electricity grid. This technology is used mainly for pumping systems or for households (Solar Home Systems) and small commercial and public services, besides of cost-effectiveness is positive in rural areas in comparison with expanding the grid

In Brazil installed photovoltaic potency remains residual, at an estimated total of 15 MWp [20], though the trend is towards growth as new installations are set up under the auspices of the Light for All (Luz para Todos), program headed by the Ministry for Mines and Energy – MME,[9] particularly so as to supply electricity to isolated communities in Brazilian Amazon.

Brazil is privileged in terms of solar radiation. The National Energy Plan 2030 reproduces data from the Solarimetric Atlas of Brazil, and registers radiation levels of between 8 and 22 MJ/m^2 per day, with the lowest variations occurring from May through July, from 8 to 18 MJ/m^2 dia [21]. Fig. 6 illustrates the variation of daily solar radiation in Brazil, indicating that the highest rates are observed in the Northeast region, varying between 5.7 and 6.1 kWh/m^2 per day, particularly in the São Francisco Valley. Even the regions with the lowest rates of radiation present major energy potential, and small-scale use of solar power is already widespread.

By way of comparison, these amounts are close to the solar radiation in India, where the highest levels are to be found in the western region of Rajasthan (4–7 kWh/m^2 day) [4] and are significantly higher than the levels encountered in Germany, 2.22–3.33 kWh/m^2 day [22].

More recent data indicates that the installed photovoltaic potency in Brazil is 20 MWp as of 2010, with 235 kWp connected to the network in experimental systems [23]. In terms of the cost of photovoltaic systems, there is considerable variety on the international market, of between 5 and 10 US$/Wp, taking into account the total cost of the installed system. These amounts do not however necessarily reflect the reality in Brazil. The cost of photovoltaic systems has declined continuously over the last decades, a tendency which is likely to continue in the future.

The International Energy Agency [24] illustrates the reduction in costs over the past 20 years on the international scene, pointing to a 50% fall over the last decade. Furthermore, Clean Edge [25] forecasts that the prices of solar energy will fall from US$ 5.50–US$ 7.00 Wp to US$ 3.02–US$ 3.82 Wp by 2015 and to US$ 1.43–US$ 1.82 Wp by 2025.

A significant portion of the photovoltaic systems existing in Brazil was installed under the auspices of the Program for Energy Development of States and Municipalities – PRODEEM, launched by the federal government in 1994. Since it was established, funding totaling US$ 37.25 million has been provided for 8956 projects and 5.112 kWp (kilowatt-peak) of potency. Drawing on PRODEEM's

[7] Brazil currently has net imports of 3 million TOE/year, and share of 0.5% of total world imports. At the other end of the scale are the US, Japan, China and Germany with 19.1%, 7.2%, 5.5% and 3.3% share of world imports, respectively [9].

[8] Recent discoveries of offshore oilfields at the pre-salt layer off the Brazilian coast staved off the possibility of an oil shortage in the near and medium term and Brazil is likely in the next few years to become a net exporter of oil. Brazil is forecasted to rise significantly in the ranking of countries with the world's largest reserves of oil and gas, if preliminary estimates as to accumulations at the pre-salt layer are confirmed. In 2010 Brazil had reserves calculated at 26,930 million barrels of oil [16]. The Ten Year Expansion Plan 2009–2019 [11] states that current oil production stands at 2 million barrels/day, expected to increase by the end of the decade to 5.1 million barrels/day. Brazil is therefore expected to considerably increase oil exports, reaching 2.2 million barrels/day in 2019.

[9] Studies underway at the Ministry of Mines and Energy (Working Group for Distributed Generation from Photovoltaic Systems–GT-GDSF) indicate a change in the current pattern. The group is studying the requisites and incentives applicable to photovoltaic systems connected to the network with a view, in the near future, to there being incentives for the use of photovoltaic panels with a potency range of 2–5 kWp, installed on the roofs of Brazilian homes, as occurs in the US, Japan and Germany. The initial project is to install 120 photovoltaic screens with an estimated potency of 1 kWp, distributed in several regions of the country.

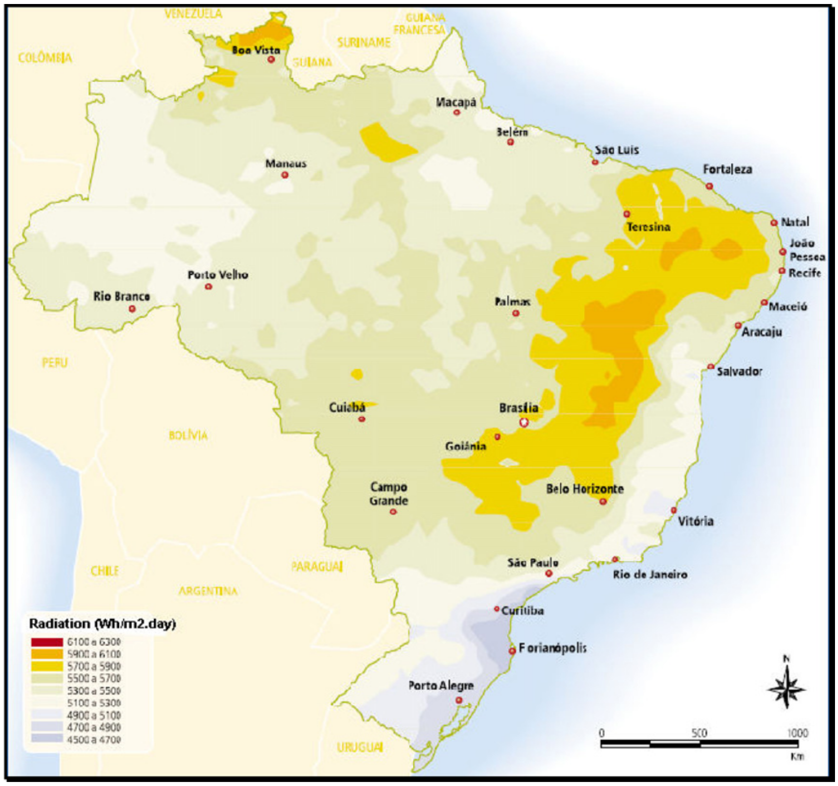


Fig. 6. Daily global solar radiation – typical annual average (Wh/m^2 day).

Source: ANEEL [21].

costs in implementing panels for energy, public lighting and pumping purposes the approximate costs of the program are estimated at US$ 7.28 Wp.

3.2. *Wind power*

Wind power is widely considered to be one of the most promising natural sources of energy. This is mainly due to the fact that it is renewable, clean, widely distributed globally, generates energy which free of emissions and has progressively low implementation costs.

In countries which have small hydrographic networks, wind power already plays a fundamental role as possibly the only clean and efficient energy source. In countries such as Brazil, which have a large hydrographic network, wind power may become significant in the future, in that it does not consume water, a resource that is increasingly scares and will also become subject to increasingly tighter controls.

Over 30,000 large scale wind turbines are in operation in the world, with an installed capacity of approximately 13,500 MW. The International Committee on Climate Change forecasts the installation of 30,000 MW, by around 2030, and this forecast may be increased in the light of the sale of "Carbon Credits". In Denmark, wind power contributes 12% of the total energy generated, in Northern Germany the contribution of wind power already exceeds 16%. The European Union has set a target of the generation from wind power of 10% of all electricity produced by 2030 [26].

According to the Global Wind Energy Council [27] in 2009 world capacity for the generation of electricity from wind was approximately 158 GW. Europe has the lion's share of the world's installed wind power capacity, with 48% of the total. Table 2 sets out the figures on generation from wind power and the respective share of the world market. It can be seen that Brazil lags far behind the major producers such as Germany and the USA.

Table 2
Generation of wind power and share of the world market.

Position	Countries	TWh	%
1	Germany	39.71	22.4
2	USA	34.6	19.5
3	Spain	27.51	15.5
4	India	11.65	6.6
5	China	8.79	5.0
6	Denmark	7.17	4.0
7	UK	5.27	3.0
8	France	4.05	2.3
9	Portugal	4.04	2.3
10	Italy	4.03	2.3
11	The Netherlands	3.44	1.9
12	Canada	3.02	1.7
13	Japan	2.62	1.5
14	Australia	2.61	1.5
15	Austria	2.02	1.1
22	Brazil	0.56	0.3
	Others	16.19	9.1
	World	177.30	100

Source: MME [9].

The Atlas of Brazilian Wind Power Potential [28] covers the whole of Brazilian territory. Its objective is to provide information which will assist decision makers with the preliminary identification of appropriate areas for wind-power installations. Fig. 7 illustrates Brazilian wind power potential, which is concentrated in the North-Eastern and Southern regions.

Lack of consistent and reliable data has been one of the limiting factors on wind energy projects in Brazil. A significant part of the available anemometric registers may be distorted or masked by the aerodynamic influences of obstacles, relief and ruggedness of the

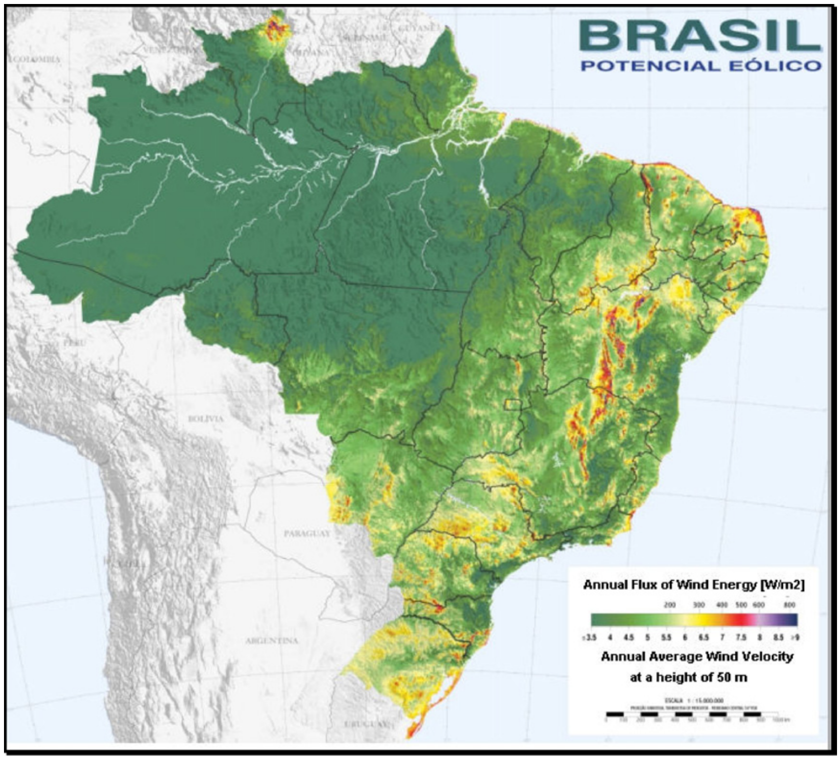


Fig. 7. Thematic map of eolic potential in Brazil.

Source: CEPEL [28].

terrain. Representative data is particularly important in Brazil in that the country has yet to make use of this abundant and renewable resource to any significant degree.

The estimated potential for wind energy generation in Brazil is 143 GW. This figure was arrived at on the basis of a study undertaken for generating towers of up to 50 m in height. Current technology enables the use of towers of up to 100 m, with the result that the actual potential is almost double the previous estimate. According to the Brazilian Association of Eolic Energy, the current installed capacity of wind energy in Brazil is 744 MW [29]. Even more recent data from the Global Wind Energy Council [30] indicates that in 2010 installed wind energy capacity in Brazil reached 931 MW, almost half of the Latin American total.

PROINFA is the leading and most far-reaching Brazilian program of investments in alternative sources of electricity. The Program is managed by Eletrobras with a view to supporting the development of projects for the diversification of the Brazilian energy matrix. The main objective of PROINFA[10] is to increase the quota of renewable energy to 10% of the offer of electricity in Brazil by 2020.

Wind power projects financed by PROINFA account for over 95% of Eolic energy installations in Brazil. Installations of 154.4 MW are currently under construction and around 560 MW remain at the development stage. It is increasingly likely that PROINFA will meet, or even exceed its forecast target of 1100 MW of wind projects [27].

The comparatively high cost of producing electricity from wind was always the main obstacle to the development of Eolic energy in Brazil, particularly given the hydraulic option with major unexploited potential and lower costs. The results of the latest renewable energy auction however indicated a sharp fall in the price per MWh of wind energy, so that the Eolic option was competitively priced, i.e. wind energy was traded at an average price of US$ 74.39/MW h, lower than sugar-cane bagasse (US$ 81.98) and Small Hydroelectric Plants (US$ 80.69). The installed Eolic capacity auctioned was 2,048 MW.

3.3. Hydraulic energy

The benefit of natural resources which becomes sources of energy production is a strategic advantage for any country. The advantages include a reduction of dependence on external supplies and consequent increased stability in terms of the supply of a service which is vital to social and economic development. In the case of hydric potential there are a further two advantages: the low cost of supply compared to other sources (coal, oil, uranium and natural gas for example) and the fact that the operation of hydroelectric plants does not provoke major emission of greenhouse gases, so that it compares favorably with the alternatives.

Several institutions in Brazil are currently analyzing the emission of greenhouse gases from reservoirs. Given the discrepancy between average flow values obtained by different institutions, as a result of variations in the methodology employed in gathering data and the frequently non-linear nature of emission processes, there is a perceived need for studies aimed at standardization of the research methods. Based on Santos et al. [32], the current state of the art indicates that in cases where hydroelectric generation is lower than 0.1 W per square meter of reservoir area, there is a possibility that GHG emissions will be higher than those arising out of a thermo-electric plant generating an equivalent amount of energy.

Santos et al. [32] consider that although hydroelectricity is not a totally clean source in atmospheric terms, the damage caused is generally lower, compared to the thermal options analyzed. This

[10] The first phase of PROINFA comprised an auction of 3300 MW of energy from wind, biomass and small hydroelectric plants (1100 MW from each technology), held in 2004. The share of wind energy in the first phase of PROINFA exceeded the expectation of the 1100 MW quota allocated to it, so that the quota was increased to 1422 MW, via re-management of the non-contracted portion of biomass projects [31].

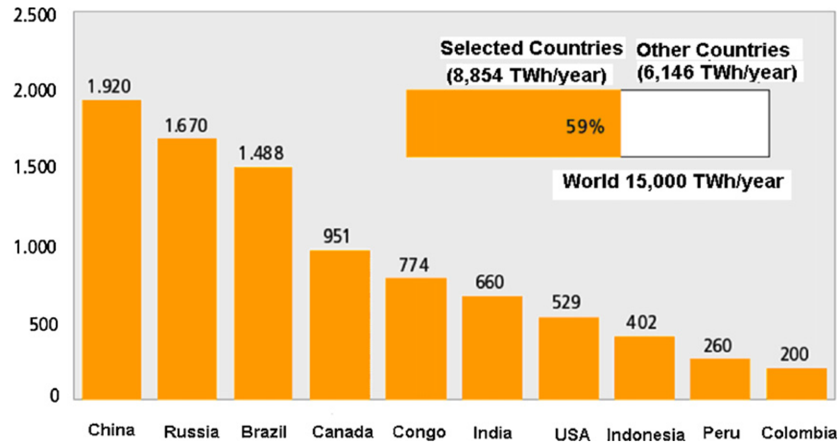


Fig. 8. Hydroelectric potential which is technically viable (TWh/year).

Source: World Energy Council, 2004 in MME [11].

Table 3
Hydraulic generation and share of the world market.

Position	Countries	TWh	%
1	China	485	15.8
2	Brazil	374	12.1
3	Canada	368	12
4	USA	250	8.1
5	Russia	177	5.8
6	Norway	134	4.4
7	India	124	4
8	Venezuela	83	2.7
9	Japan	74	2.4
10	Sweden	66	2.1
11	France	58	1.9
12	Paraguay	54	1.7
13	Colombia	44	1.4
14	Austria	36	1.2
15	Turkey	36	1.2
	Others	715	23.2
	World	3.078	100

Source: MME [9].

would indicate that opting for a hydroelectric technological route, as Brazil has done, is a reliable solution in reducing the emission of greenhouse gases in the electricity sector, when compared to the thermal option.

Brazil has over 400 large and medium-scale hydroelectric plants, which generate 93% of the country's energy. Table 3 sets out Brazil's share of the world market – 12.1% of the hydraulic generation market. The world's main generators of hydroelectric energy in 2007 were China, with 482.9 TWh, Brazil with 371.5 TWh and Canada with 368.2 TWh. Brazil still has enormous hydroelectric potential of 1488 TWh/year, which is yet to be exploited (Fig. 8). 70% of future expansion of generation is likely to occur in the Amazon region.

The basins with the greatest potential include those of the Amazonas and Paraná rivers. Within the Amazon Basin, the Rio Xingu sub-basin (18) has 12.7% of the country's inventoried potential. Other sub-basins of the Amazon which have considerable estimated potential are those of the Rio Tapajós (17), Rio Madeira (15) and Rio Negro (14). In the Tocantins Basin, the Rio Itacaiunas sub-basin and others (29) have 6.1% of the inventoried Brazilian potential. Within the São Francisco basin, the sub-basin 49 represents 9.9% of the inventoried potential. The Paraná basin contains various sub-basins with major potential, including the Paraná, Paranapanema and other sub-basins (64), with 8.1% of the country's inventoried potential. The Brazilian hydraulic potential, set out per hydrographic potential, is set out in Fig. 9.

In April 2010 an auction was held for the Belo Monte plant, which has an installed capacity of 11,233 MW, forecast investment of US$ 11 billion and a reservoir area of 440 km^2 reaching flooding index of 0.0391 km^2/MW.[11] Operational startup is scheduled for 2015. The tariff value reached US$ 44.41/MWh at the auction. The Belo Monte tariff was slightly higher than those reached in other auctions for the Jirau Hydroelectric plant (2008), with a tariff value of US$42.99 and the Santo Antônio plant (2007) with a tariff value of US$ 44.18, but it is nevertheless highly competitive when compared to the other options.

Maintaining the high participation of installed hydraulic based capacity in the energy matrix is one of the major challenges currently facing the Brazilian electricity sector. There are three main reasons for that: firstly, the need to pursue diversification of the electricity grid, as set out in governmental plans for the electricity industry, with the stated aim of increasing the safety (stability) of supply; secondly, the difficulty involved in coming up with new hydraulic projects due to a lack of studies and inventories and thirdly; the increase in legal challenges which delay the environmental licensing for hydric based plants and increase the contracting of thermal based plants (most of which burn coal or oil derivatives) at energy auctions.

3.4. Small hydroelectric plants (SHP)

Small hydroelectric plants (SHPs) are one of the main priorities of the Electricity Regulatory Agency (ANEEL) in terms of the offer of electric energy in Brazil. Given their characteristics (installed potency of between 1 and 30 MW and a reservoir area of up to 3 km^2) SHPs are ideally suited to meeting the energy demands of small urban centers and rural areas. From 1998 onwards the construction of these generating units was encouraged by a series of legal and regulatory mechanisms.

ANEEL (Regulatory Electric Power Agency) resolutions permit the entry of energy generated in the SHPs onto the electricity grid free of charge for the use of the transmission and distribution network. This benefit is available for plants which began operating up to 2003. SHPs are also exempt from the need to pay municipalities and State governments for the use of the hydric resources. In the event of their being established in the 'isolated system' of the Amazon region, they may also be entitled to subsidies from a fund set up with money from the Consumption of Fossil Fuel Account (*Conta Consumo de Combustíveis Fósseis – CCC*), in order to finance

[11] The reservoir originally planned was substantially reduced, with the flooded area decreased by 60%. Whilst the national average of areas flooded by hydroelectric plants is 0.49 km^2 per installed MW, Belo Monte will have an impact on only 0.04 km^2 per installed MW, avoiding the flooding of indigenous lands [33].

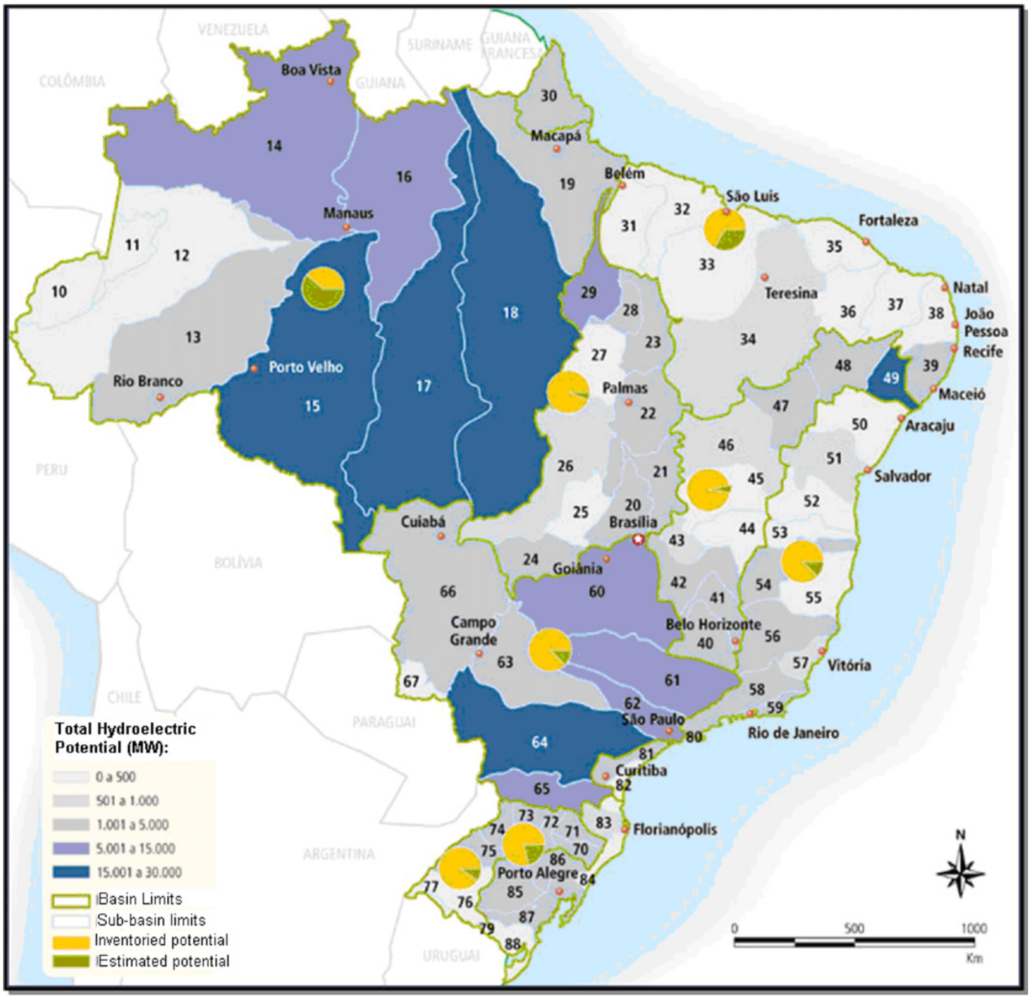


Fig. 9. Brazilian hydroelectric potential per hydrographic sub-basin.

Source: ANEEL [21].

projects which substitute diesel-oil powered thermal plants in the isolated systems of the Northern Region.

According to ANEEL (2011) data, there are 397 SHPs in operation in Brazil, with a total output of approximately 3.5 thousand MW, and a growth rate of 10% per annum. Data from the Brazilian Association of Small and Medium Scale Producers of Electricity [34] indicate that the potential output is around 25.9 GW, with an average cost between US$ 3030.00 and US$ 4242.00 per MW. Fig. 10 illustrates the geographical distribution of the plants in Brazil.

3.5. Ethanol

Ethanol is a liquid fuel aimed principally at the substitution of light oil derivatives, either for direct use in combustion engines (E100 or *flex fuel* engines), or via its addition to gasoline, up to 25% of volume, in accordance with Brazilian legislation. Ethanol may be produced from any biological primary matter which contains appreciable quantities of sugars or materials that may be converted into sugars such as starches or cellulose. For cost reasons, it is generally produced from the fermentation of sugars by enzymes produced by yeast. It is the ethanol produced from sugarcane, however, which is the most economically viable in Brazil.

The Brazilian government has adopted various measures aimed at taking full advantage of the advantages of ethanol. One such measure was the Brazilian Ethanol Program (Proálcool).

The Proálcool program successfully implemented large scale substitution of petroleum derivatives. It was developed as a means of avoiding increased dependence on foreign currency loans in the wake of the 1970s oil crisis. From 1975 to 2000, almost 5.6 million hydrated alcohol powered vehicles were manufactured. Furthermore, the Program substituted between 1.1% and 25% of pure gasoline with anhydrous alcohol in a Brazilian fleet of over 10 million vehicles, thereby reducing, during this period, the emission of around 110 million tons of carbon (contained in CO_2) and the import of approximately 550 million barrels of oil, promoting foreign exchange savings of approximately 11.5 billion dollars.

In recent years the technology of flex fuel motors has given new impetus to the internal consumption of alcohol. A car which can be powered by gasoline, alcohol or a combination of both was introduced in the country in March 2003 and soon became popular with consumers. Nowadays the option is already available for all models, and biofuel vehicles now outnumber those powered by gasoline, on the internal market. Given the high price of oil on the international markets there is widespread expectation that this share will increase even further. The current relationship of prices means that the user of biofuel models generally prefers alcohol.

There is presently no price regulation of the alcohol fuel markets (either hydrous or anhydrous) at the production, distribution and resale stages, with prices being determined by supply and demand [36].

Efforts are being made worldwide to come up with a solution that conciliates the increasing demand for energy with the need to reduce the respective environmental impacts, particularly greenhouse gases. In this respect the *flex fuel* car is competitive,

Fig. 10. Geographical distribution of the SHPs.

Source: ANEEL [35].

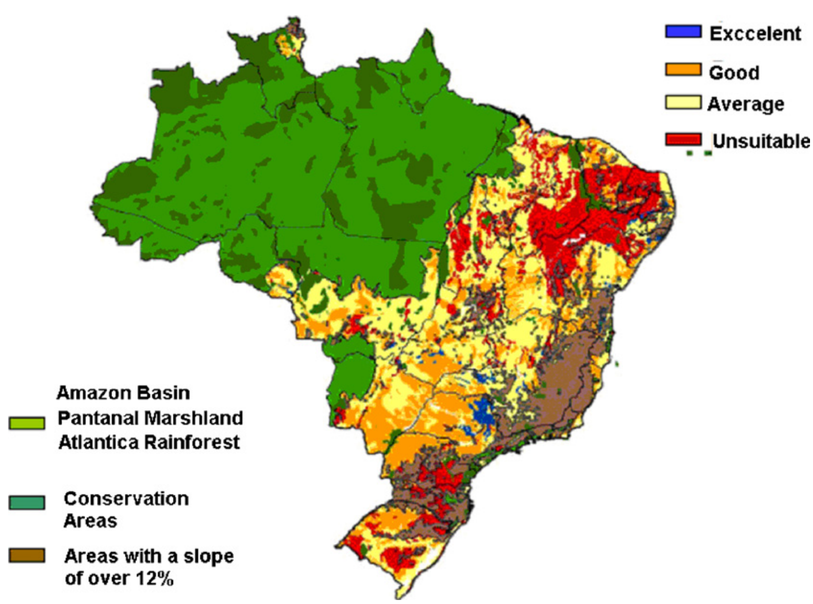


Fig. 11. Potential for sugarcane production (without irrigation).

Source: MCT [39].

Table 4
Production of ethanol and other biofuels (Otto cycle) and participation in the world market.

Position	Countries	TEP (million)	%
1	USA	13.3	49.9
2	Brazil	8.7	32.5
3	Germany	1.5	5.7
4	China	0.8	3.2
5	Canada	0.7	2.5
6	Sweden	0.3	1.2
7	France	0.3	1.0
8	Colombia	0.1	0.5
9	India	0.1	0.5
10	The Netherlands	0.1	0.5
11	Spain	0.1	0.4
12	Austria	0.1	0.3
13	Thailand	0.1	0.3
14	Poland	0.1	0.3
15	UK	0.1	0.3
	Others	0.2	0.8
	World	26.6	100

Source: MME [9].

both in terms of cost and consumption, as well as emissions. In the case of Brazil, allied with the low cost of production of ethanol from sugar cane, this leads to a scenario of expansion of the production and consumption of ethanol [36].

Of all the sources of renewable energy used in Brazil, biofuels are particularly evident. Brazil has the world's most competitive program of development and production of this non-oil derived liquid, and has the second largest share of the world ethanol production market (Table 4).

Of ethanol is also prized for its low price, low emission of pollutant gases and for being a viable alternative to oil in the transport sector. Nowadays it represents 15% of the total of all fuels used in fuel engines, whilst oil accounts for 22.8%. The Brazilian Ministry of Mines and Energy forecasts that these figures will reach 19.8% for alcohol and 23.3% for oil by 2030. [34]. Furthermore, in addition to being less pollutant, ethanol has export potential. According to the National Petroleum Agency [37] 3.3 billion liters out of the 26.1 billion liters produced were sent abroad in 2009[12] with the main destinations being Holland, Jamaica and India.

The National Energy Balance [13] indicates that in 2008 there was a significant increase of 20.3% in the production of ethanol in Brazil, to 27,140,405 m^3. Approximately 65% of this total was hydrous alcohol: 17,563,496 m^3. In comparative terms there was a 22.8% increase in the production of this fuel in relation to the earlier period. This increase was due to the major market penetration of *flexfuel* vehicles which enable the consumer to decide which is the most economic – gasoline or hydrous alcohol.

There was an increase of 16% in the production of anhydrous alcohol, which is blended with A gasoline to form C gasoline, reaching a total of 9,576,909 m^3. The reason for this increase is the increase in the anhydrous content of the blend, as of July 1, 2007, when the percentage increased from 23% to 25% hydrated alcohol [13]. Note that 57.6% of national production is concentrated in the State of São Paulo, with Minas Gerais being the second largest national producer with an 8.7% share [37].

Environmental issues subject to recent analysis include the emission of greenhouse gases associated with a change in patterns of soil use, with the loss of original cover when sugar cane fields are implanted, as well as indirect de-forestation caused by the occupation by sugar cane of land previously used for grazing. According to [38], in the case of ethanol in Brazil, it is unlikely that

[12] In 2008 the US was the main export destination for ethanol (1.7 billion liters) however between 2008 and 2009 US imports fell 83.31%.

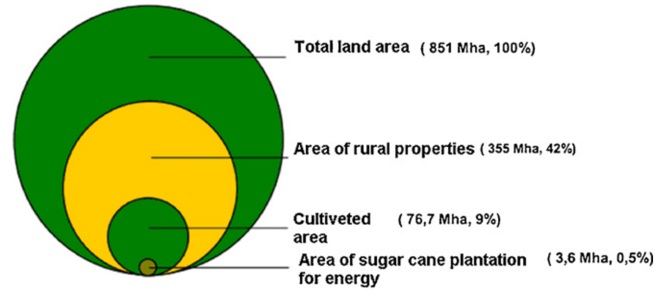


Fig. 12. Use of land in Brazil.
Source: Nogueira [38].

there will loss of forest cover associated with ethanol production in that the expansion of sugar cane plantation has taken place basically in areas previously used for low productivity grazing or for annual crops such as soya, aimed mainly for export and with lower magnitude root system and biomass cover of the soil than is the case with sugar-cane.

The Brazilian Ministry of Science and Technology [39] has, based on the country's soil and climatic conditions, mapped areas which have potential for sugar cane cultivation, with or without irrigation, excluding areas which are subject to environmental restrictions or which have a declivity of over 12% (due to the stated aim of 100% mechanized harvesting). This present study has used the map of areas with potential for sugar cane cultivation without irrigation and added to it areas of environmental preservation such as indigenous reservations, ecological parks, military zones and others, as set out in Fig. 11.

In terms of indirect deforestation caused by the expansion of sugar cane cultivation, it is worth noting that Brazil, like other countries located in humid tropical regions of the planet, has land available for significant expansion of agriculture and the capacity to sustainably produce food and bioenergy without the need to sacrifice its forests. Sugarcane fields destined for the production of fuel correspond, in Brazil, to a reduced portion of the agricultural area and the country's territory, as can be seen in Fig. 12. The production of ethanol from sugarcane does not call for deforestation, unlike the expansion of cattle rearing/agricultural activities, particularly in the Amazon region, which call for tighter legal controls and monitoring [38].

The sugar-alcohol sector in Brazil is one of the most competitive in the world, with the best rates of productivity and industrial yield as well as low production costs. The industry is mature. With oil costing over U$ 30.00 per barrel Brazilian ethanol is a highly competitive substitute. It is also important to bear in mind that all gasoline sold in Brazil must, by law, contain 25% anhydrous alcohol. Fig. 13 sets out the production costs of ethanol in various regions of the world.

The use of sugarcane as raw material in the production of ethanol is another advantage Brazil has over other producing countries. Sugarcane has better production costs, greater productivity per cultivated area, a more favorable energy balance and greater reduction of greenhouse gas emissions. In the last 30 years agricultural production has more than doubled, passing from 3.2 m^3 of ethanol per liter to almost 7 m^3 per hectare [40].

The generation of electricity using bagasse as fuel in co-generation systems which are highly efficient in meeting the mechanical potency and heating needs of the ethanol processing system is another segment of the ethanol business. For decades, such production of electricity was limited to meeting the needs of the agroindustry in question. However with the evolution of regulation of the electricity sector it became possible to enhance the development of co-generation systems so that they began to

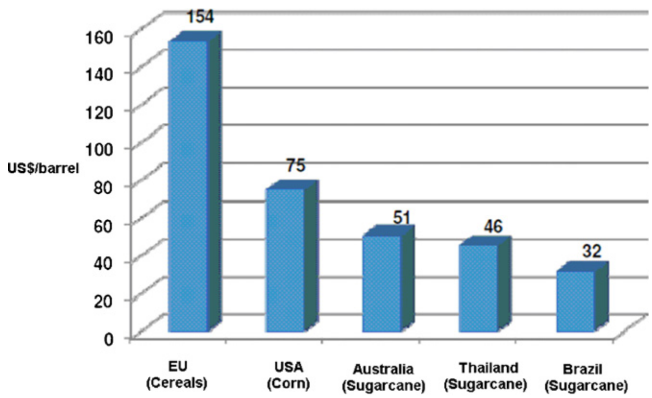


Fig. 13. Cost of ethanol production.
Source: Nogueira [38].

generate excess energy for the grid, with increasing economic importance, contributing, in countries like Brazil, to the supply of commercial electricity. During the 1980s the usual conditions in which the boilers used at Brazilian plants operated enabled the generation of excess electricity of around 10 kWh/tc (ton of processed cane), whilst nowadays most productive units are able to generate 28 kWh/tc with the most modern plants generating 72 kWh/tc. With the use of part of the harvested cane straw and with fine tuning of the industrial process, the surplus electricity can reach up to 150 kWh/tc. Nogueira [38] states that in early 2008 the installed capacity in sugar and bioethanol plants in Brazil was 3.1 GW and it is possible that the generation of electricity from bagasse for the grid may reach 15 GW by 2015.

3.6. Biodiesel

Biofuels are derivatives from renewable biomass that may partially or totally substitute in combustion engines or other types of energy generation fuel derived from oil and natural gas. The two main liquid biofuels used in Brazil are ethanol extracted from sugarcane and, increasingly, biodiesel, which is produced from vegetable oil or animal fat and added to petroleum diesel in varying proportions.

In theory, biodiesel is capable of substituting fossil-based diesel in any the latter's applications. However in practice the entry of this fuel into the Brazilian energy matrix is likely to be gradual, and focused on specific markets, in order to ensure the irreversibility of the process.

The use of biodiesel may be divided into two distinct markets – the automotive market and the stationary plant market. The latter is basically made up of electricity generation installations with certain specific and regional specifications. They typically generate energy in locations which are not supplied by the regular grid, in remote regions of the country. In terms of the volumes involved they are not significant, but they may provide significant savings on transport costs as, more importantly, promoting the social inclusions and citizenship rights of the local communities.

The automotive market may be sub-divided into two groups, one made up of major consumers with geographically restricted circulation, such as urban (city) transport companies, railways and river transport service providers, amongst others. The second parcel of the automotive market is made up of retail consumption, via the sale of fuel at traditional points of sale. This group includes interstate cargo and passenger transport, light vehicles and general consumers. Note that in Brazil most biodiesel is directed towards use in vehicles, with use to generate energy being residual.

As required by Law 11.097 of 2005, the Brazilian government launched the National Program for the Production and Use of Biodiesel (PNPB) to encourage production by small producers and regional social and economic development. Additional regulations were introduced requiring the addition of 2% Biodiesel (B2) to vehicle diesel as from January 2008, increased to 3% in July 2008 and 4% by July 2009. The original legislation made provision for the addition of 5% as from January 2013,[13] but this date was brought forward to January 2010 at the request of the Brazilian authorities.

In March 2011 there were 69 biodiesel production plants authorized by the National Petroleum Agency (ANP) to operate in the country, corresponding to a total authorized capacity of 17,415.95 m^3/day. Of these 69 plants, 60 are authorized to sell the biodiesel produced,[14] which corresponds to 16,344.25 m^3/day of authorized sale capacity[15] [42]. Fig. 14 illustrates the geographical distribution of the biodiesel plants in Brazil, highlighting the major concentration in the South-Eastern region. Note that 67.7% of Brazilian production comes from the State of São Paulo [37].

The planting of oilseeds and the process of production of biodiesel consume much less energy than is generated during the burning of fuel, i.e. the energy balance is highly positive. In order to transform biodiesel into energy the oxide cycle of carbon is closed, in other words, the CO_2 emissions generated in the burning of biofuels is set off by the uptake of carbon through photosynthesis during plant growth.

The synergy between the oilseed complex and the alcohol fuel sector gives rise to the need to increase alcohol production. The production of biodiesel consumes spirit alcohol, via trans-esterification by ethylic route, which generates increased demand for the product. The biodiesel market also stimulates the development of the sugar-alcohol sector, generating fresh investment, employment and income.

The biodiesel productive chain generates some sub-products which require further close analysis in future studies, in that they are a key factor in enhancing the economic viability of the production of this fuel. The main sub-products include: glycerin, lecithin, press cake and oilseed meal.

There are innumerable oilseed plants in the country which are suitable raw material for the production of renewable fuel, such as soya, palm oil, castor beans, babassu, sunflower and peanut. Brazil possesses multiple sources of raw material for the production of bio-diesel, distributed throughout the country, as is shown in Fig. 15, which highlights the predominant source in various regions. Note, however, the predominance of production based on soy oil (81.36%). Also worthy of note is the share of bovine fats (13.36%) and cotton oil (4.11%).

The reserves of areas which are cultivable without the need for deforestation, in the largest country in South America, are so immense that the production of biomass as a source of generation of vegetable oils and consequently of biodiesel could be considerably expanded without harm to the environment.

In terms of demand there are broad possibilities of use for biodiesel in urban, rail, road and water transport of cargo and passengers, energy generators, stationary engines, etc. In terms of supply there are numerous high yield oilseeds, associated with a

[13] The legislation makes provision for the possibility of higher percentage blends, and even the use of pure biodiesel (B100) with the prior authorization of the National Agency for Petroleum, Natural Gas and Biofuels (ANP).

[14] Biodiesel must comply with physical-chemical specifications established by the Brazilian government through the ANP, which is responsible for authorizing the functioning of the biodiesel industries and monitoring production and sale. Biodiesel cannot be sold and blended with mineral diesel unless it meets the quality standards, which the ANP monitors with modern systems such as the molecular marker [41].

[15] Authorization has also been given for the construction of a further 4 biodiesel plants and expansion of the capacity of a further 7. Once the work is completed and operating licenses issued the total authorized capacity may increase by 2040.03 m^3/day.

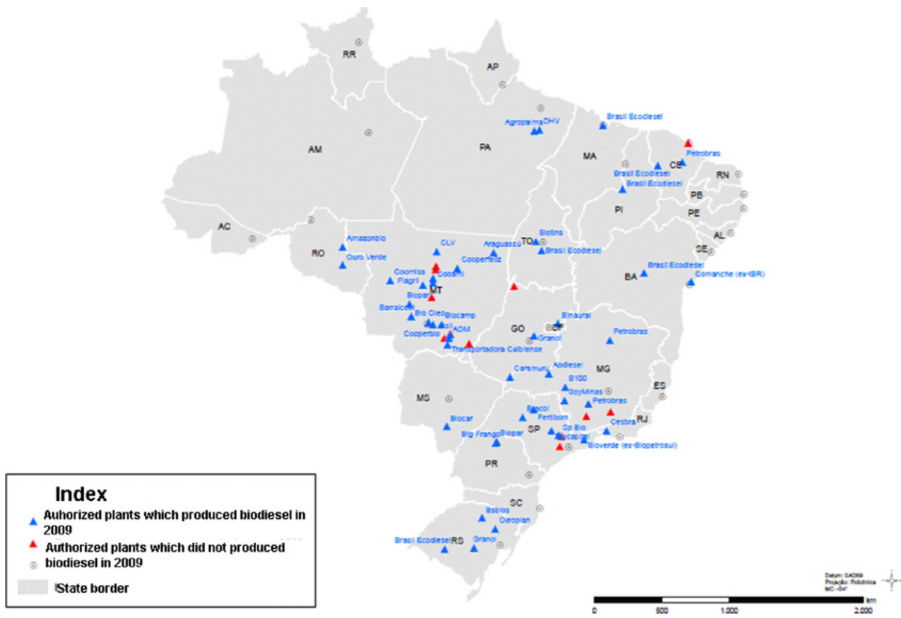


Fig. 14. Geographical distribution of biodiesel production – Brazil (2009).

Source: ANP [37].

Table 5
Crops of potential interest for biodiesel production in Brazil.

Crop		Oil content (%)	Agricultural yield (ton/ha)	Oil yeld (liter/ha)
Common name	Scientific name			
Sesame	*Sesamum indicus*	38–40	0.8	1200–620
Sunflower	*Heliantus annus*	39–48	1.5–2.0	2510–2100
Castor	*Ricinus Comunis*	42–45	0.6–2.5	450–270
Peanut	*Arachis hipogaea*	39–48	1.4–2.5	1680–950
Palm	*Elaeis guineensis*	18–26	10.0–22.0	5900–3000
Soybean	*Glycine max*	17–20	1.5–3.0	1000–700
Rapeseed	*Brassica napus*	37–46	1.7–2.0	1100–690
Cottonseed	*Gossypium hirsutum*	16–18	1.7–3.0	700–490
Jatropha	*Jatropha curcas*	24–26	1.0–5.0	520–350
Coconut	*Cocos nucifera*	52–60	1.0–5.0	1100–700

Source: Nogueira [43].

huge contingent of cultivable land in Brazil which has not yet been farmed. Palm oil is outstanding in terms of yield of biodiesel per hectare, when compared to other crops. Table 5 sets out the potential yield in biodiesel per hectare of the main oilseed species in Brazil. Even though soy oil does not have the best per hectare yield, its productive park is organized and competitive, geared towards the export sector. It is currently the dominant raw material in the production of biodiesel.

Actions, such as the National Program for the Production and Use of Biodiesel (PNPB) directed at the supply of an internal biodiesel market serve as an economic signal to the market of the increasing demand for biofuel, stimulating increased private investment in the sector. The PNPB [41] acknowledges that the economic stimulus for the production of biodiesel in Brazil lies in the evolution of this internal market and the conquest of foreign markets, so that it falls to public policies to provide conditions for the industry to function efficiently and achieve the aims of promoting social inclusion and development of more underdeveloped regions, in line with sustainability in the broadest sense of the word. In this sense Brazil is distinct in terms of its enormous potential, albeit that its market share remains small compared to that of Germany and the US (Table 6).

Table 6
Production of biodiesel and share of the world market.

Position	Countries	TEP (million)	%
1	Germany	3.698	49.9
2	USA	1.597	32.5
3	France	1.194	5.7
4	Brazil	0.301	3.2
5	The Netherlands	0.276	2.5
6	Spain	0.271	1.2
7	UK	0.269	1.0
8	China	0.264	0.5
9	Austria	0.212	0.5
10	Italy	0.180	0.5
11	Portugal	0.134	0.4
12	Sweden	0.102	0.3
13	Belgium	0.087	0.3
14	Greece	0.086	0.3
15	South Korea	0.084	0.3
	Others	0.529	0.8
	World	9.285	100

Source: MME [9].

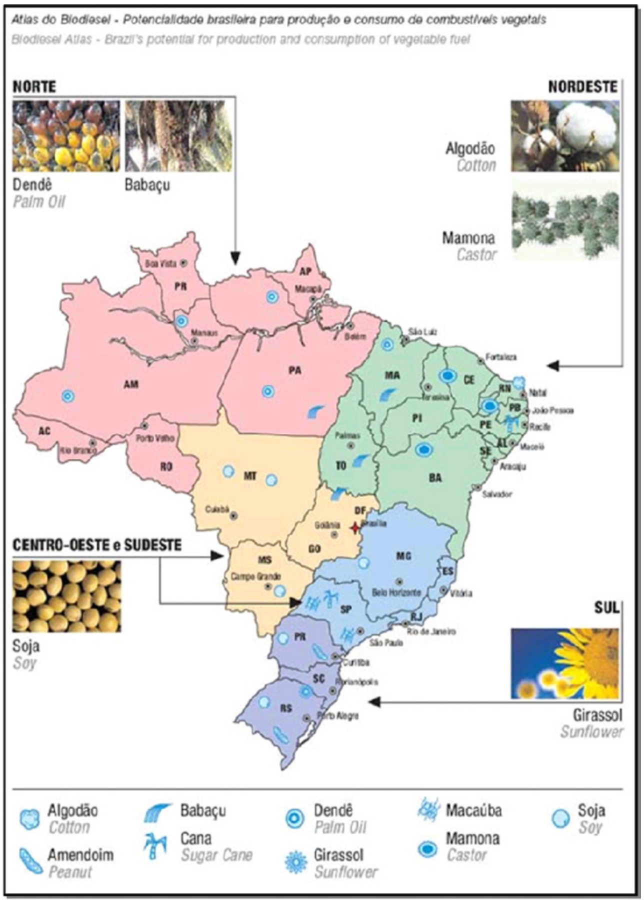


Fig. 15. Geographical distribution of the main raw materials for the production of biodiesel – Brazil (2009).
Source: ANP [37].

4. Market development strategies and future perspectives

The hydraulic energy and ethanol markets already have a consolidated internal market and have high visibility abroad. Solar energy, wind power, small hydraulic plants (SHP) and biodiesel, on the other hand, call for official measures in order to promote the markets which, despite the huge potential for growth, remain incipient. In this sense the Ten-Year Expansion Plan 2010–2019 [11] makes provision for investments of around U$ 28.2 billion from 2009 to 2019, in eolic energy, SHP and biomass, and US$ 39 billion in bio fuels.

The incentives provided to renewable energy sources may be generically classified into systems based on price and systems based on quantities. The main mechanisms may be divided into three categories [44]:

- The *Feed-In* system (based on price), which is used by Germany, Denmark and Spain, and constitutes the principal incentive system;
- The Auction System (based on quantity), used by the United Kingdom, Ireland and France (up until 2000). This system consists of establishing a total number of alternative sources of renewable electricity to be installed into the system and after several auction sessions, the projects with the lowest costs are selected;
- Green Certificate/Quota system (based on quantity), used in some European countries such as Austria, Denmark, Sweden, Belgium and in thirteen US states. The quota system requires electricity supply companies to produce or purchase quotas of energy derived from alternative renewable sources. This system, in addition to promoting de-centralized production also favors the green certificate market.

The Brazilian government recently adopted the auction system as a planning tool for the expansion of supply, to be applied to major hydro-electric plants and to biomass, wind power, SHP and biodiesel. The auction system rewards efficiency in the process, starting with the choice of location through to the technology to be used, relying on specific supply contracts such as those used in wind farms, for example. One of the main reasons for opting for auctions is that they render the process more transparent for society as well as seeking the fair price, the aim being to encourage as many prospective bidders as possible and to avoid collusion.

Dutra [44] states that despite the fact that the auction system has a slower rate of growth than the feed in, it has the important characteristic of the tendency to lead to a reduction in the premiums paid for renewable generation, in that under the auction system the process tend to cover the marginal costs of the project.

In the Brazilian auction system the criterion of lowest tariff is used to determine which is the winning bid in the auction, in other words the successful bidders will be those who offer electricity at the lowest Mega-Watt/hour price in order to meet the forecast demand. The German Auction Model[16] (Descending Price) is that which is most often followed, applying a fixed volume of auctioned MW for which purchasers can select the desired fraction for offer.

It is worth recording that the bids offered at the last wind energy auction in 2010 exceeded the expectations of all the agents of the electricity sector, i.e. the government, the trade association, manufacturers and consultants. The general expectation was of a rate of approximately US$ 133 per MWh in order to render the auction viable. The actual result was markedly different, corresponding to an average discount of 21.5% on an established ceiling price (US$ 114) set by the regulatory agency. The factors which explain this price include the exemption from tax liability of approximately 30% of the investment and the high capacity factor of the parks put out for tender[17]; the physical location of the sites, close to the electricity network, thereby reducing transmission costs and losses; more appropriate sites, reducing construction costs and the costs of transporting purchased to the site; the possibility of selling carbon credits; favorable financing terms offered by the National Social and Economic Development Bank (BNDES); the exclusive auction for wind energy, thus making a scale possible; the stimulation of internal competition in view of the imminent consolidation of the wind energy market; the increase in value of the Real against the Dollar, a reduction in the cost of imports and an indication of future growth in Dollar receipts; the world economic crisis which delayed the entry of new wind farms in the developed countries, leading to an excess supply of equipment, part of which was redirected to those countries which had emerged from the crisis more rapidly, such as Brazil.

[16] There are four main types of auction: open, with ascending price, known as the: “English” auction, descending price or “Dutch”/”German”, and closed–with a selaed or closed envelope bid – first or second price. Garcia [45] considers however each premise of the auction, such as, for example: collusion, predatory practice, reserved price, political problems, errors in the project, credibility of the rules, market structure, and the situation alters in favor of one or other type of auction. Each bidder has a maximum to offer, an evaluation as to how much to auctioned object is worth and how much the other bidders will offer, in addition to as bidding strategy. Thus the result of the auction, who wins and the price paid, is strongly influenced by the information available to the bidders.

[17] At some sites the capacity factor were over 50%.

The recent extension of the growth of wind energy in Brazil has produced many advantages. Not only has it led to a reduction in costs, an expansion in supply without involving greenhouse gas emissions, and a diversification in the matrix and in technological understanding, but there has also been a marked interest on the part of various multinational companies in establishing themselves in Brazil for the manufacture and/or assembly of equipment and services of high aggregate value, leading to an increase in employment opportunities and encouraging universities and technical colleges to include courses oriented towards wind energy. Equally, and frequently underestimated, the question of the decentralization of the use of energy resources is a promising means of development for local authorities which have stagnated economically. Among other things the increase in taxes from wind farms has enabled progress to be made in reinvigorating the economies of these local authorities, with increased investment in infrastructure. This geographical redistribution in the use of energy resources indicates a new division of income, and is associated with limited socio-environmental impact when compared with thermal options.

With regard to solar energy, as opposed to wind energy, there is still a long way to travel down this road in order to expand and consolidate the market. The generation of electrical energy through solar panels is generally still restricted to small projects in isolated areas of the Amazon region. Certain measures to reduce and/or exempt taxes on imports were introduced with a view to testing the technology for decentralised supply, in conditions peculiar to the social and energy requirements of isolated locations in Amazonia.

The National Program for Universal Access and Use of Electrical Power ("Light for All") has the target of making supply universal by 2011 and is considering a solution for domestic supply by means of photovoltaic panels, not simply an extension of the grid. It is estimated that of the 12 million Brazilians who have been supplied with electric power in recent years under the program, 50,000 of them were supplied by photovoltaic panels. It is calculated that there are still 275,000 people who live in extremely isolated locations in the Amazon region, the majority of whom could still be supplied through photovoltaic systems [46].

This solution has a specific market for small isolated projects, and could be a hybrid solution when used in conjunction with diesel motors and/or wind generators, on appropriate sites. One of the main restrictions relates to the high cost of installation and maintenance, but it is necessary to compare the generating cost in these localities with the cost to the utility company, because the latter is a substitute service, on the basis that each generator, by means of the photovoltaic panel, is an "offer cell" by the utility company.[18] When the question is approached from this aspect, the cost per kW of reference comes close to the economic viability of the project.

Although in its early stages, the development of the solar option in Brazil makes the supply of electricity possible in isolated regions of Amazonia, thereby integrating communities and bringing better living standards to families, as well as assisting in reducing social exclusion.[19]

With regard to SHPs, the target set out by the Ten Year Energy Plan [11] indicates that the installed SHP base in Brazil should reach 7 GW by 2019, but it is still possible to increase this installed capacity. There are still some challenges, especially relating to tariffs, among which are, apart from a greater stimulus to the PCH market, more attractive borrowing terms from the National Bank for Economic and Social Development (BNDES), greater flexibility in the procedure for obtaining consents for the project at all stages of the process, bearing in mind that in some cases there can be a waiting period of more than 5 years, and the need to maintain regulatory stability in the sector. On the other hand, the technology is well developed and widely diffused and the market is growing.

With regard to the production of sugar cane and ethanol, it is clear that this is excessively concentrated in the South East region of Brazil. It is believed that decentralisation with a view to minimising regional differences would be possible if planning and research programs were undertaken in areas which currently have potential in terms of soil, climate and drainage, but which lack specific technologies, such as, for example, modified varieties of sugar cane. In the agricultural field, emphasis should be given to studies for the genetic improvement of sugar cane, mechanised harvesting and planting, fertilisation techniques, cultural traits and other aspects. Among new technologies studied in the industrial field, it is worth emphasising the introduction of acid and enzyme hydrolysis and the use of bagasse (crushed sugar cane) and straw, which permits an increase in production without enlarging the cultivated area.

In order to encourage the production of bio-diesel, auction sales have been set up by the National Association for Petroleum (ANP). These auctions are regulated by instruments issued by the competent bodies: the National Council for Energy Policy (CNPE), the Ministry of Mines and Energy (MME) and the ANP, and only companies who hold the Social Fuel Seal (Selo Combustível Social) may take part in them. According to the results of the 19th bio-diesel auction, the maximum reference price was US$ 1364.70/m^3, the average agreed price was US$ 1023.52/m^3, and the total volume sold was 615,000 m^3 [47]. It should be noted that in the auctions of bio-diesel there was a fall in the value of the auctions compared with previous auctions, but it is still not possible to say if this fall was the result of an increase in the efficiency of the production process, as well as the expansion and structuring of the internal market for bio-diesel.

5. Conclusion

Consumption of natural gas, oil and coal will continue increasing throughout the world, and consequently the emission of greenhouse gases related to the burning of these fuels. Current trends in the consumption of fossil fuels are unsustainable and cannot be maintained in the long term, both from an environmental standpoint and from an economic and social point of view [48].

Currently renewable energy accounts for a figure of 12.9% of the world supply of primary energy, while in Brazil this figure is 45.9% [13]. This statistic indicates that Brazil has during recent decades maintained its comparative advantage over the rest of the world in terms of the use of renewable sources of energy. Brazil represents more than 90% of investment made in Latin America in 2008 [49], and investment in renewable energy in Brazil in 2008 amounted to US$ 10.8 billion, compared with US$ 155 billion invested worldwide.

The past strategy of Brazil in cultivating and consolidating its internal market, particularly in the ethanol and hydro-electric sectors, has produced significant results. Advantages of scale were achieved, with a reduction in costs and an increase in productivity, coupled with technological development, and many other positive factors were associated with the process. Added to this, in the context of climate change, have been the efforts of Brazil to

[18] The residential tariff together with taxes is the price of electricity to the end consumer (0.29 USS/kWh in the city of Rio de Janeiro in 2011). It should be noted that this price will tend to increase in the next few decades. On the other hand, the generating cost from installation and operation of photovoltaic systems has been falling over the last few years, and the trend is a continuing fall, raising the possibility in the near future for the end consumer to be also a supplier, as for example by the use of solar roof panels on private homes.

[19] The lack of access to modern sources of energy increases poverty, particularly in rural areas, where opportunities are scarce. The implementation of policies directed towards the eradication of poverty should include the expansion of access to electricity, largely because of its social consequences [2].

adopt voluntary targets[20] for the reduction of its greenhouse gas emissions.

On the other hand, vigorous action is required to exploit the potential of other renewables. The country has enormous potential for the production of wind power, in particular in the North East, and for solar power in isolated areas of Amazonia, but these technologies involve generating costs which are still high. These costs have a tendency to fall, while on the other hand the marginal costs of traditional sources are increasing, meaning that renewable energy sources may be competitive in the near future. Investment in research, development and innovation is decisive for the adoption by Brazilian firms of programs which are highly intensive in technical knowledge, even if initially partial, so as to enable Brazil to approach the level of countries at the cutting edge of technological development. In addition, the "pre-salt" (recent discoveries of large deposits of oil and gas at great depths off the coast of Brazil) offers a window of opportunity to encourage, by cross subsidies from oil revenues,[21] investment in research, development and innovation oriented towards renewable sources of energy, thus expanding the opportunities for a low carbon economy.

In summary, Brazil has demonstrated exemplary policies, which have made inclusive economic growth possible, as well as encouraging renewable sources of energy and a reduction of deforestation in the Amazon region, which has made a positive contribution to questions related to climate change, especially in the field of energy.

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[20] Brazil has adopted voluntary targets for reducing its emissions of greenhouse gases. This target varies between 36.1% and 38.9% by 2020, in relation to emissions in 1990. Under the voluntary proposals for reduction, the Brazilian government intends to make cuts of between 975 million and 1 billion tons of carbon gas by 2020 compared with the projected emissions without cuts. The targets provide for a reduction of 20.9% in CO2 emissions and a reduction of 80% in deforestation in Amazonia. And 3.9% with a reduction of 40% in deforestation of the Cerrado, making 24.8% of total emissions. For livestock farming, the reduction figures vary between 4.9% and 6.1%. For this purpose, actions include recovery of pasture land, arable-livestock integration, direct planting and biological fixing of nitrogen. In the energy sector, the reduction figure varies between 6.1% and 7.7%, focusing on energy efficiency, increasing use of bio-fuels, expansion of the supply of hydroelectric energy and alternative sources, such as, for example, bio-electricity and wind power. In the steel industry, with a reduction figure varying between 0.3% and 0.4%, the focus will be on the substitution of charoal from deforestation by planted trees.

[21] Under federal law, a part of oil revenues must be invested in research, development and innovation (The Oil and Natural Gas Industry Fund). The objective is the encouragement of innovation in the oil and natural gas production process, the training and qualification of personnel, and the development of projects in partnerships between companies and universities, institutes of higher education and research centres in Brazil, with a view to increasing production and productivity, the reduction of costs and prices, and an improvement in the quality of products in the industry.

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